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(54) **METHODS OF FORMING RUGGED SEMICONDUCTOR-CONTAINING SURFACES**

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(52) **U.S. Cl.** ..... **438/399**; 438/255; 438/398; 438/964

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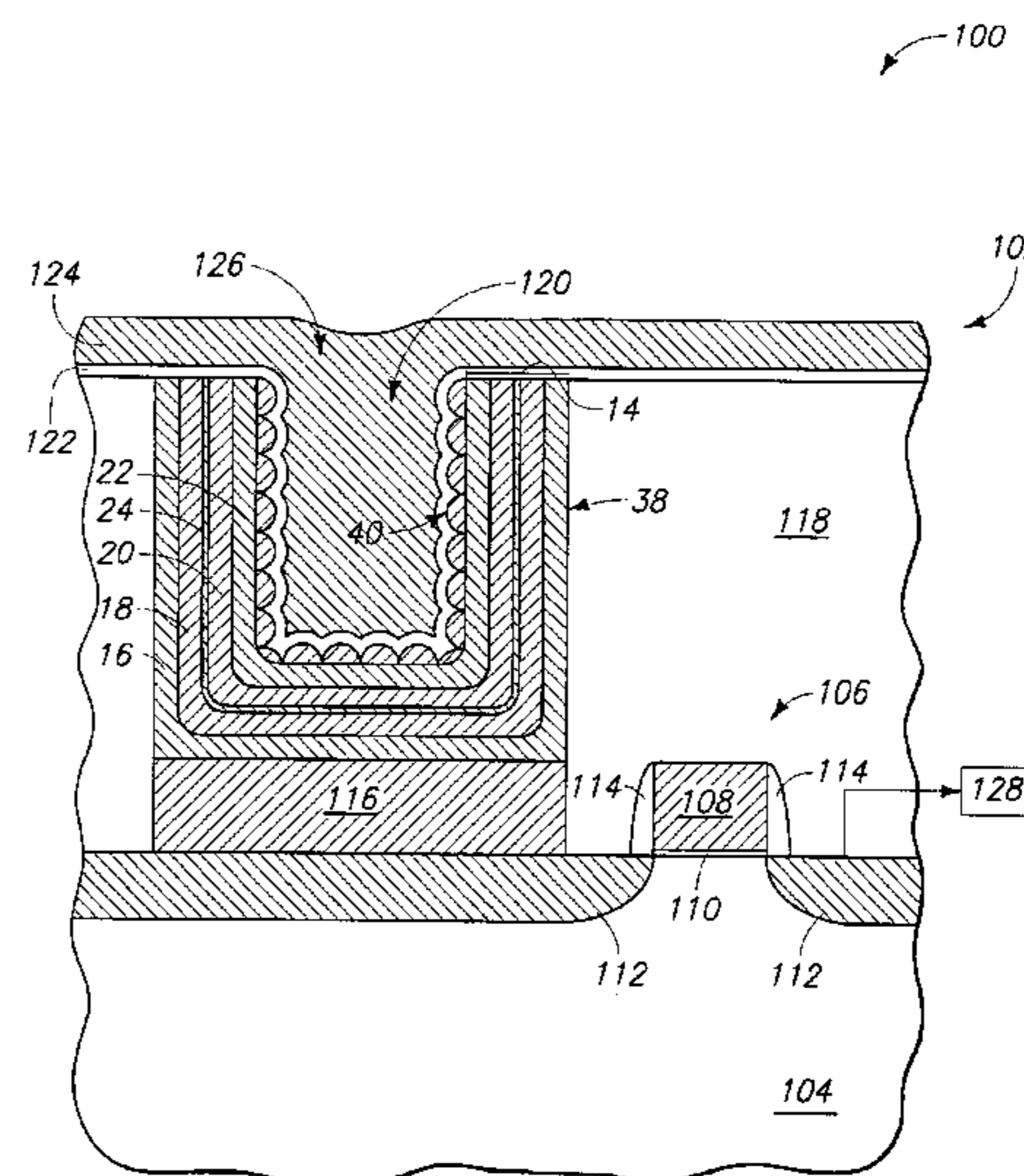
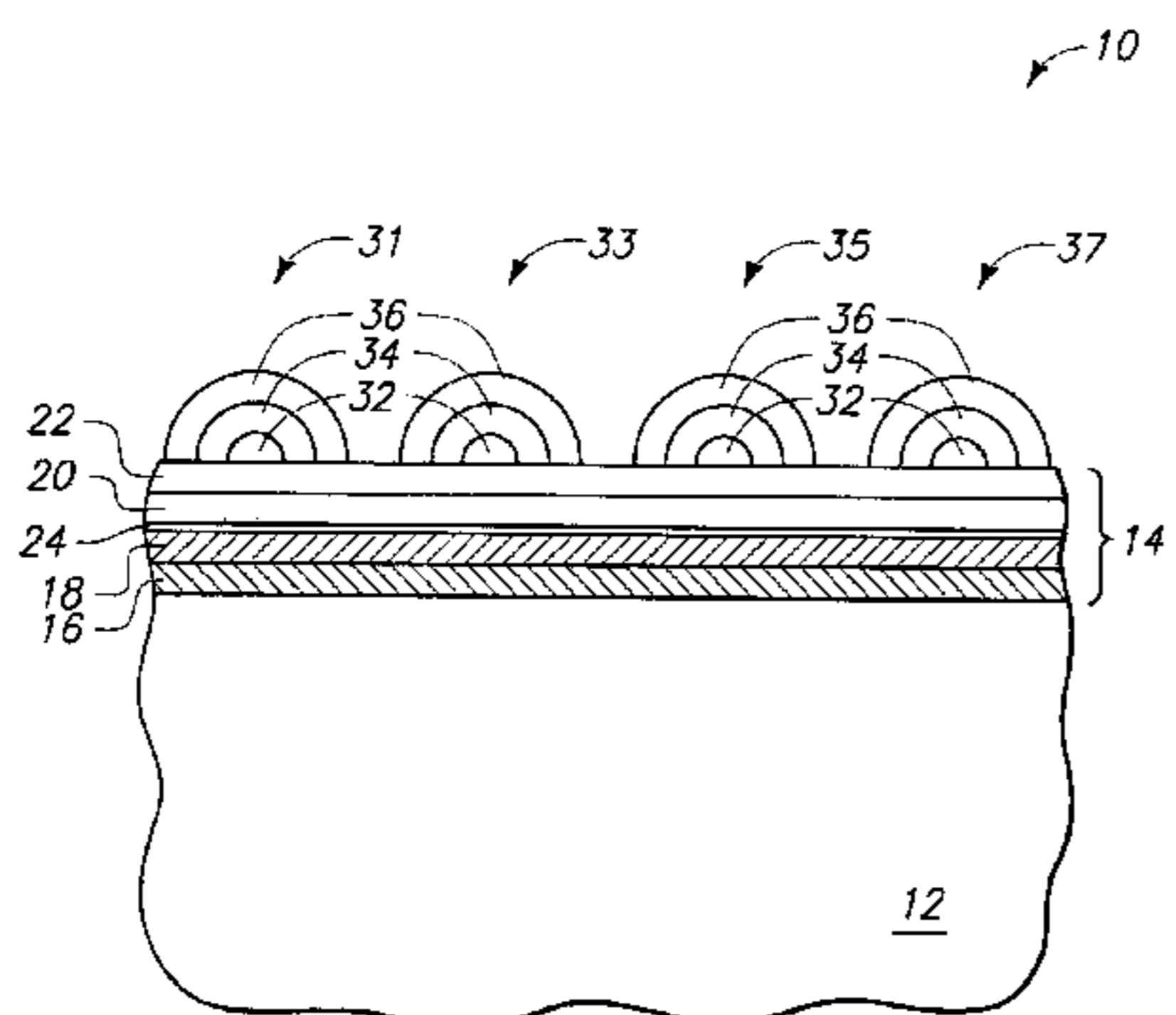
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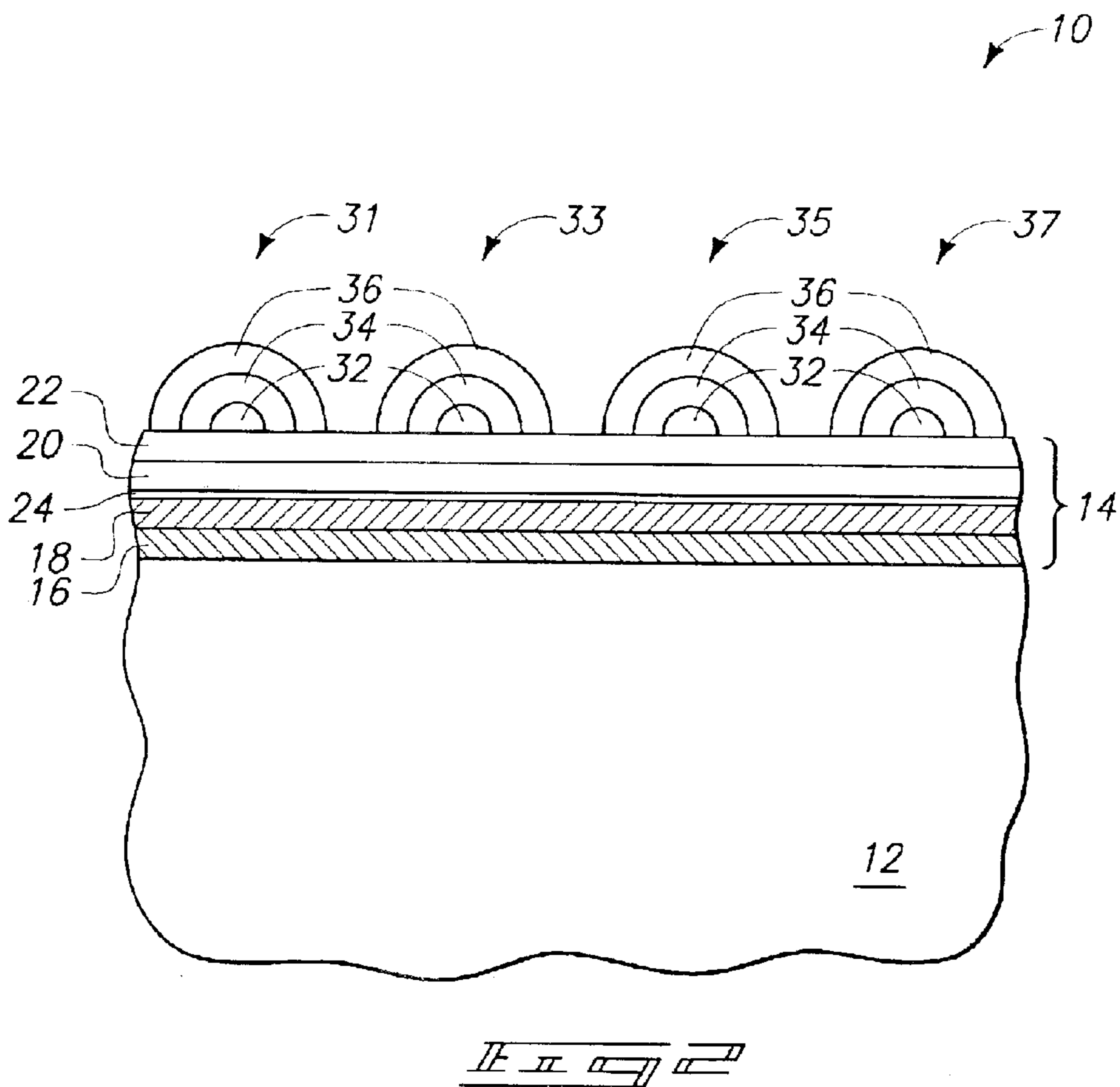
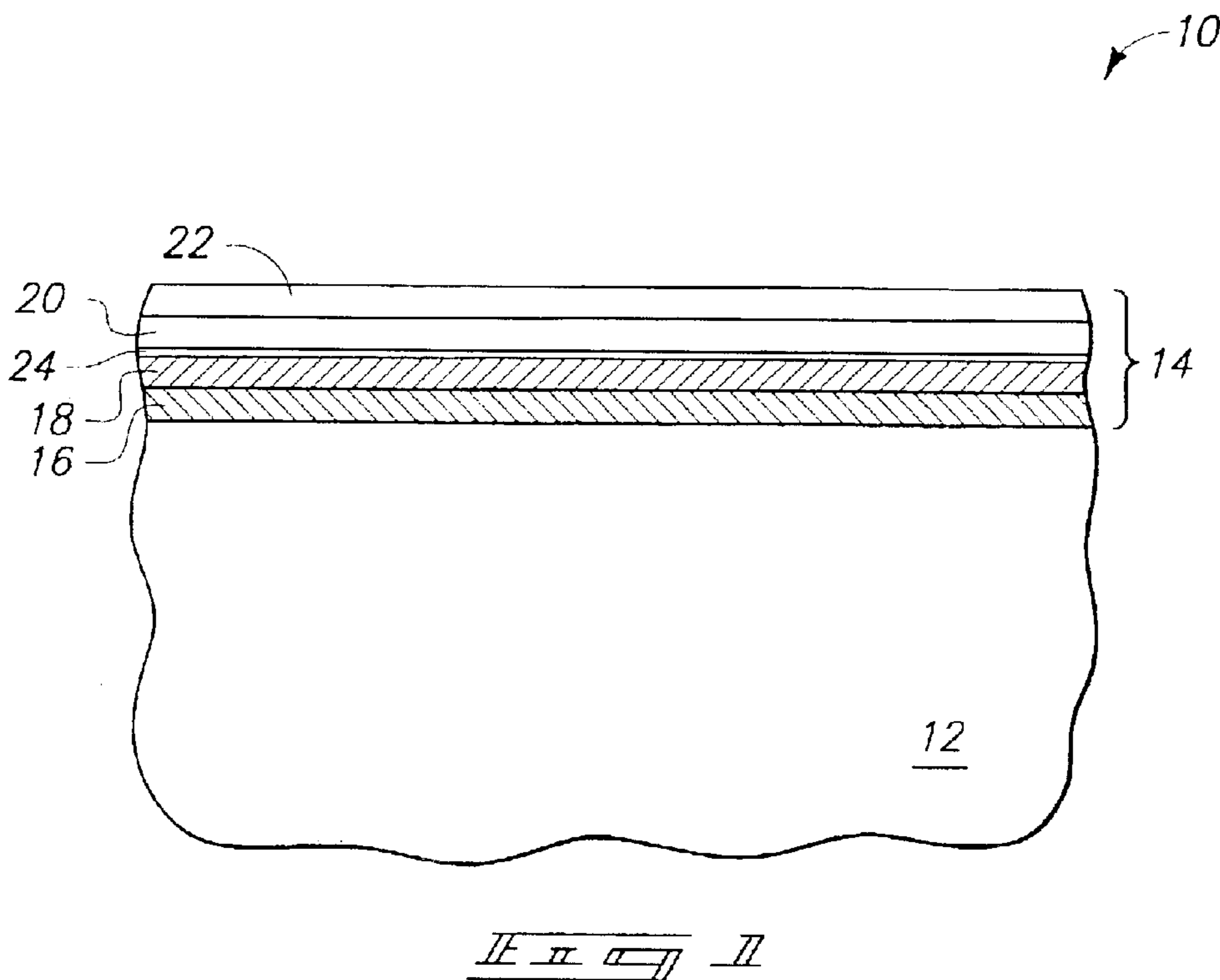
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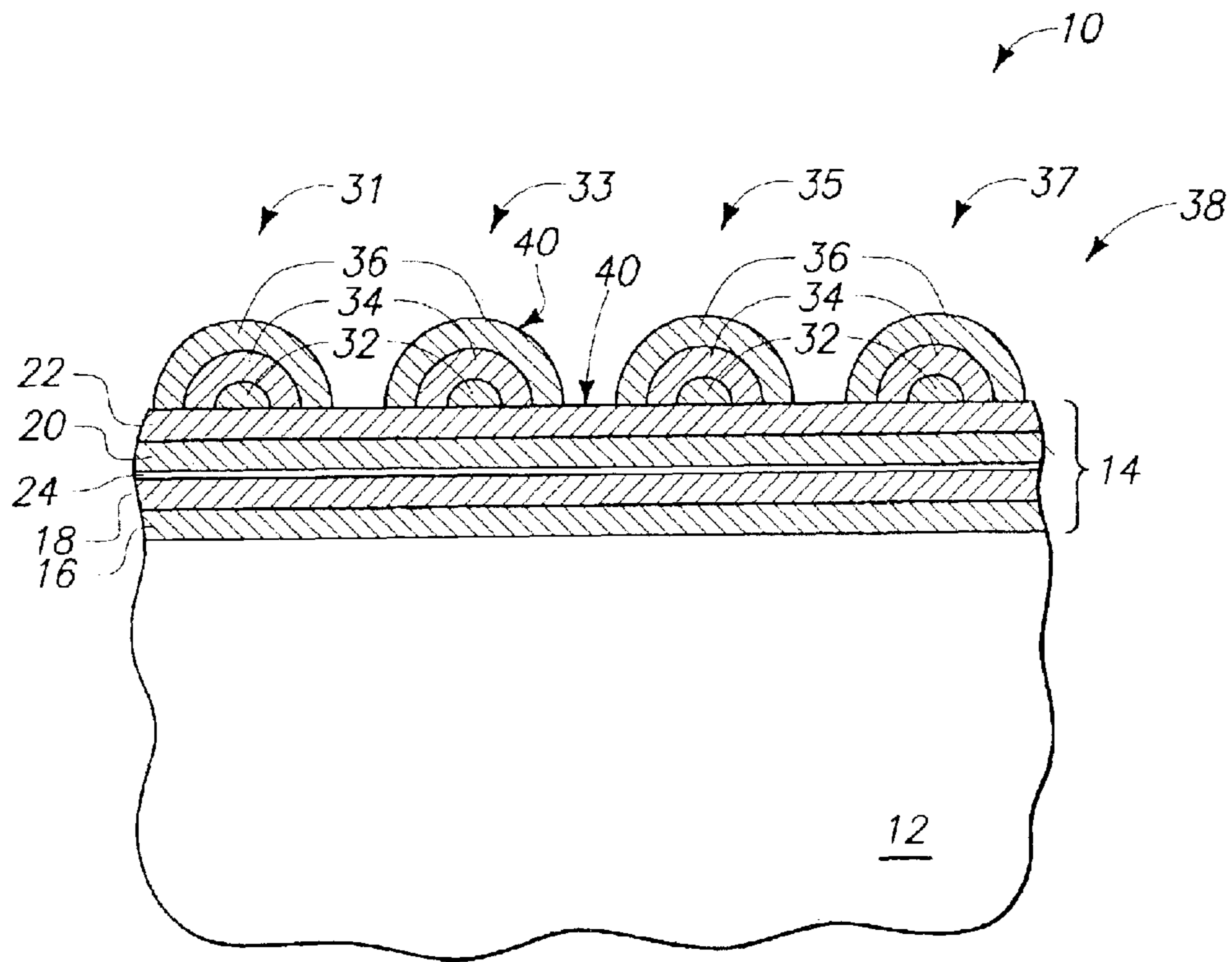
(57) **ABSTRACT**

The invention includes a method of forming a rugged semiconductor-containing surface. A first semiconductor layer is formed over a substrate, and a second semiconductor layer is formed over the first semiconductor layer. Subsequently, a third semiconductor layer is formed over the second semiconductor layer, and semiconductor-containing seeds are formed over the third semiconductor layer. The seeds are annealed to form the rugged semiconductor-containing surface. The first, second and third semiconductor layers are part of a common stack, and can be together utilized within a storage node of a capacitor construction. The invention also includes semiconductor structures comprising rugged surfaces. The rugged surfaces can be, for example, rugged silicon.

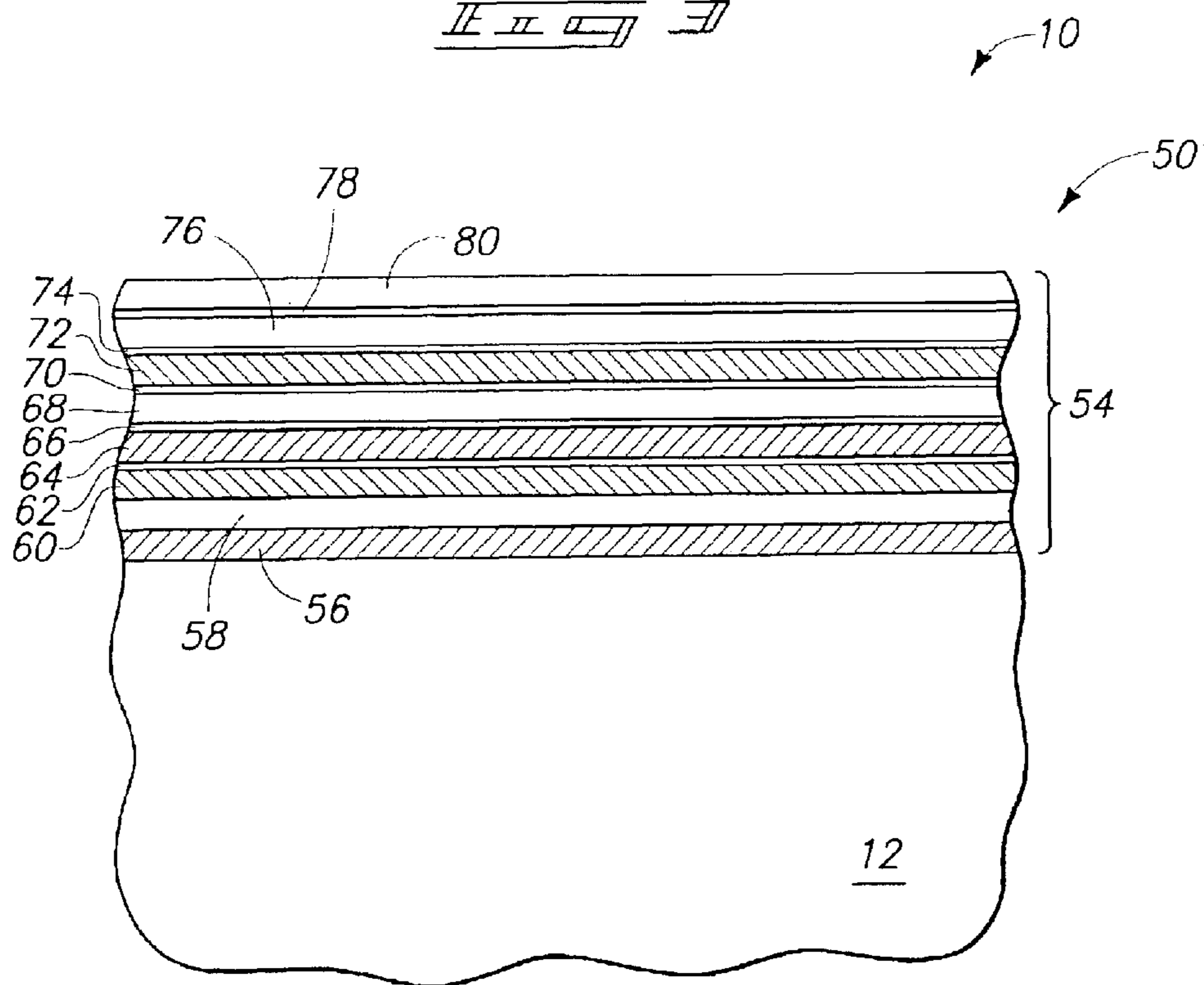
**45 Claims, 5 Drawing Sheets**







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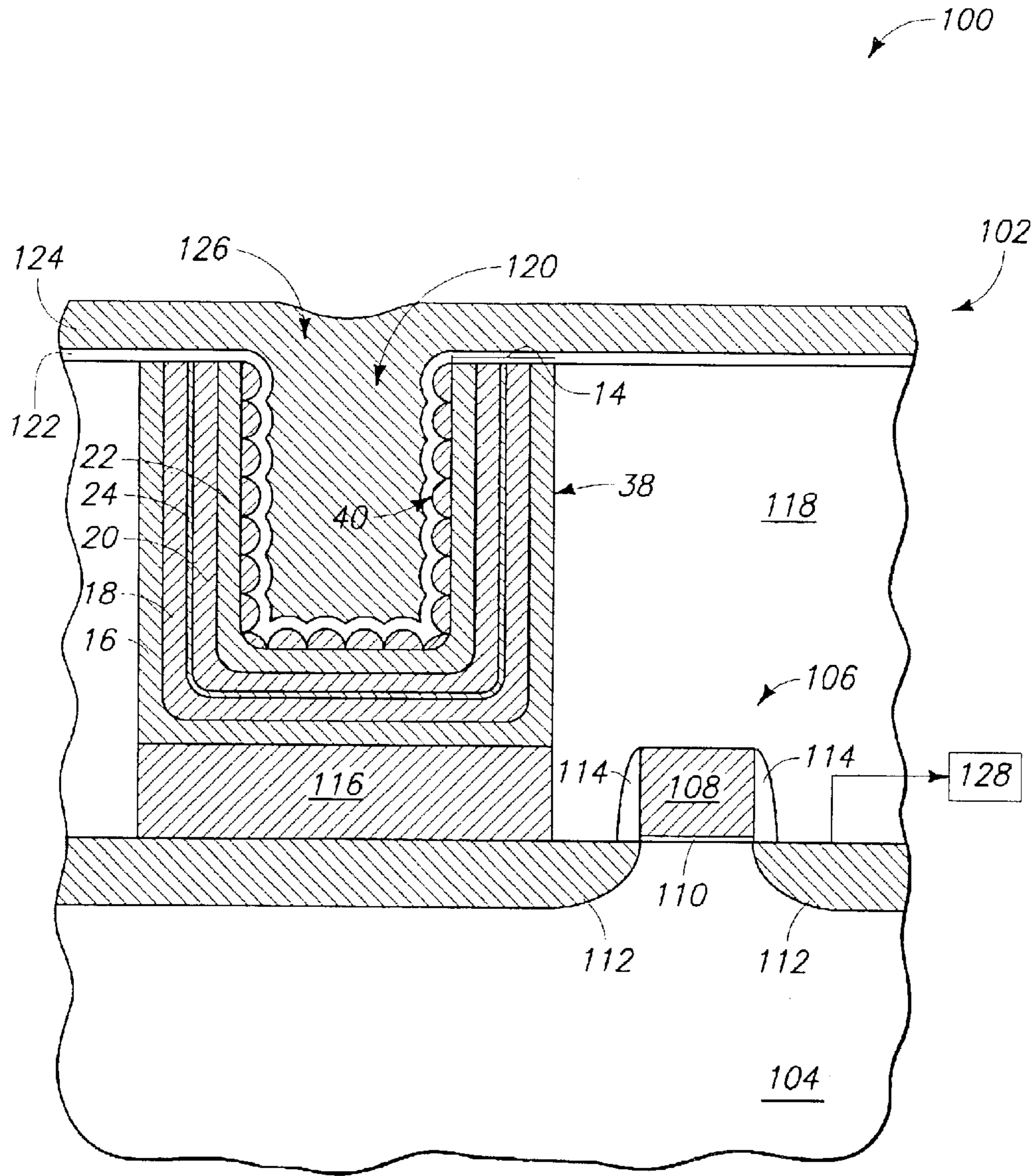
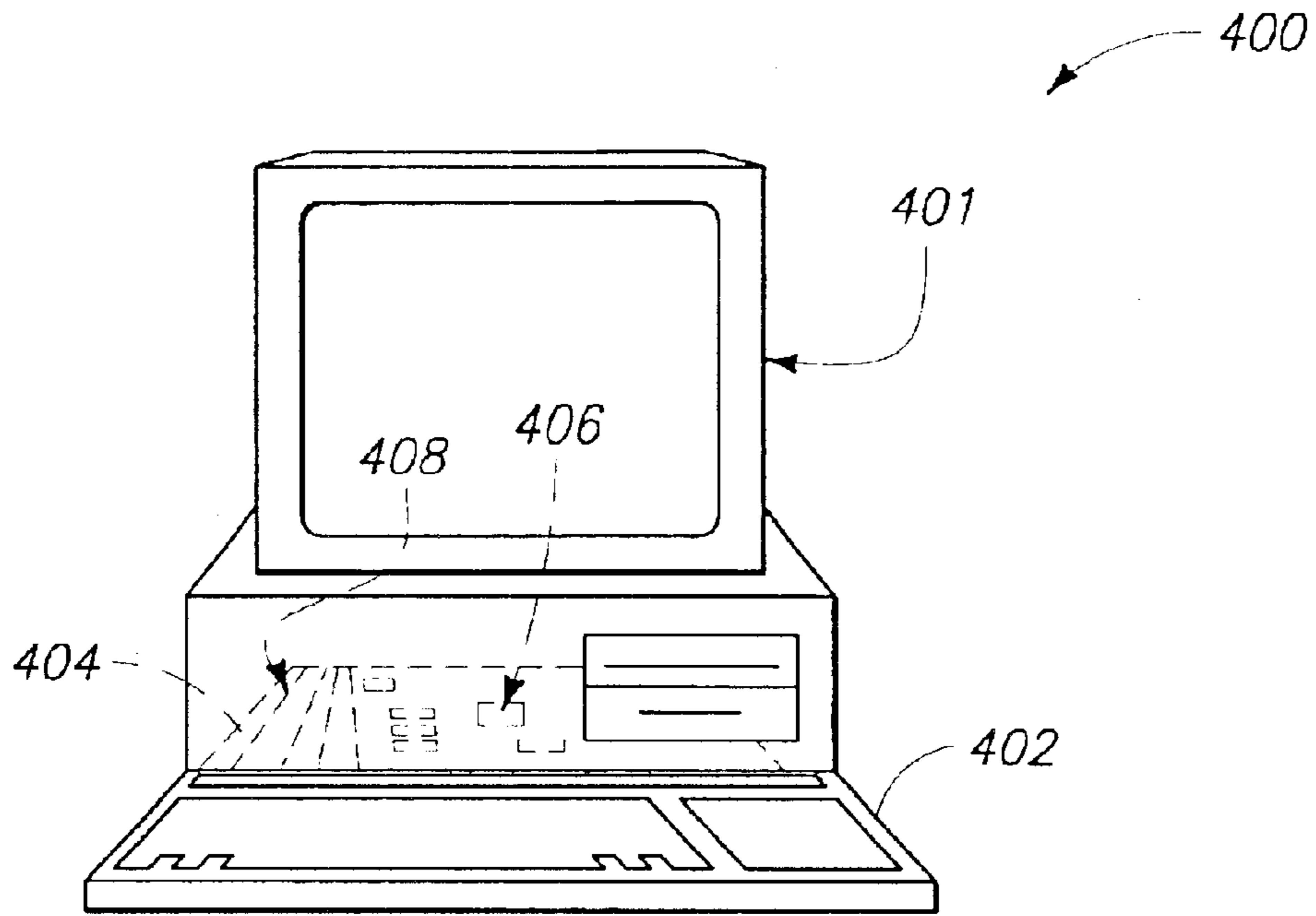
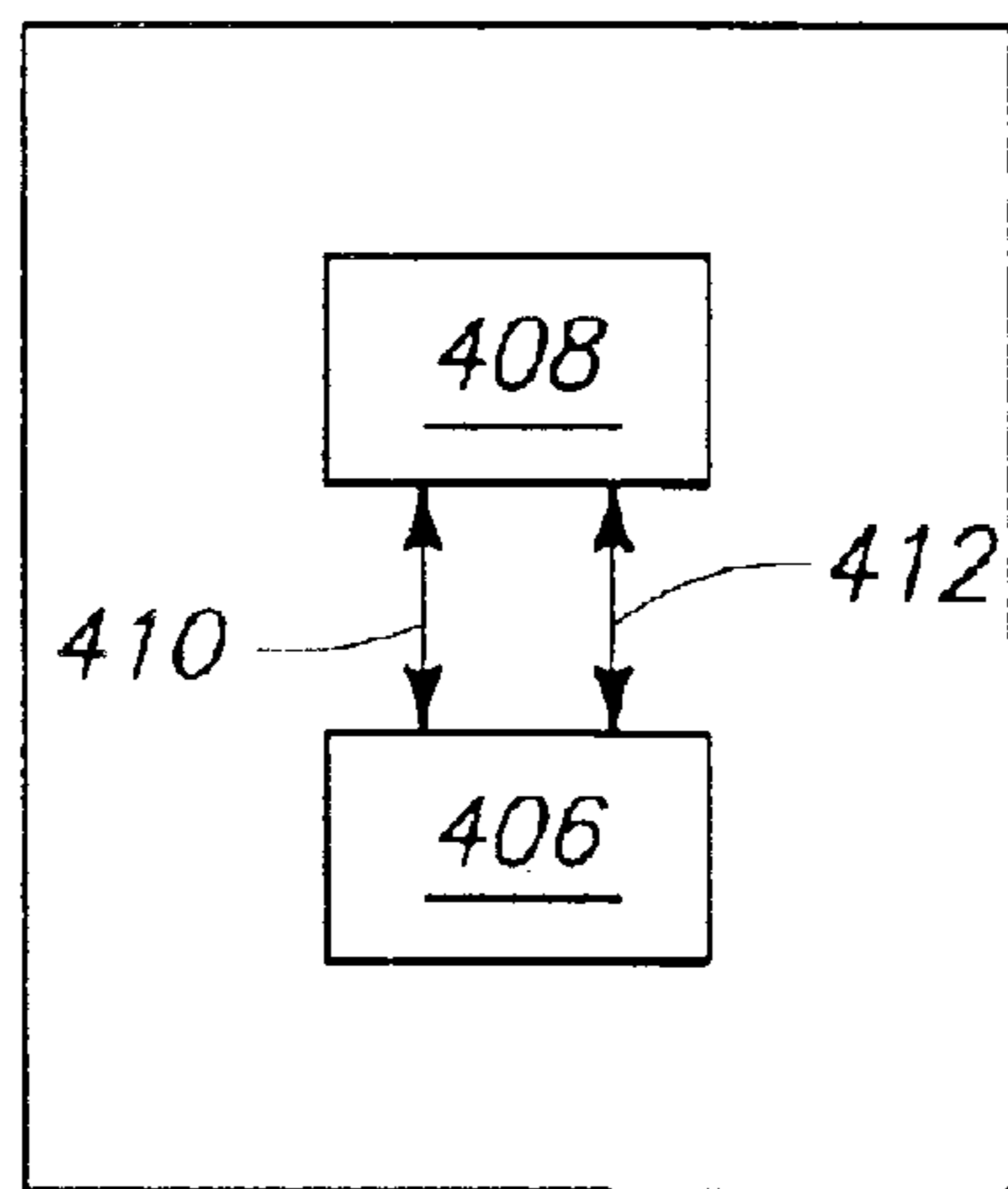


FIG. 5

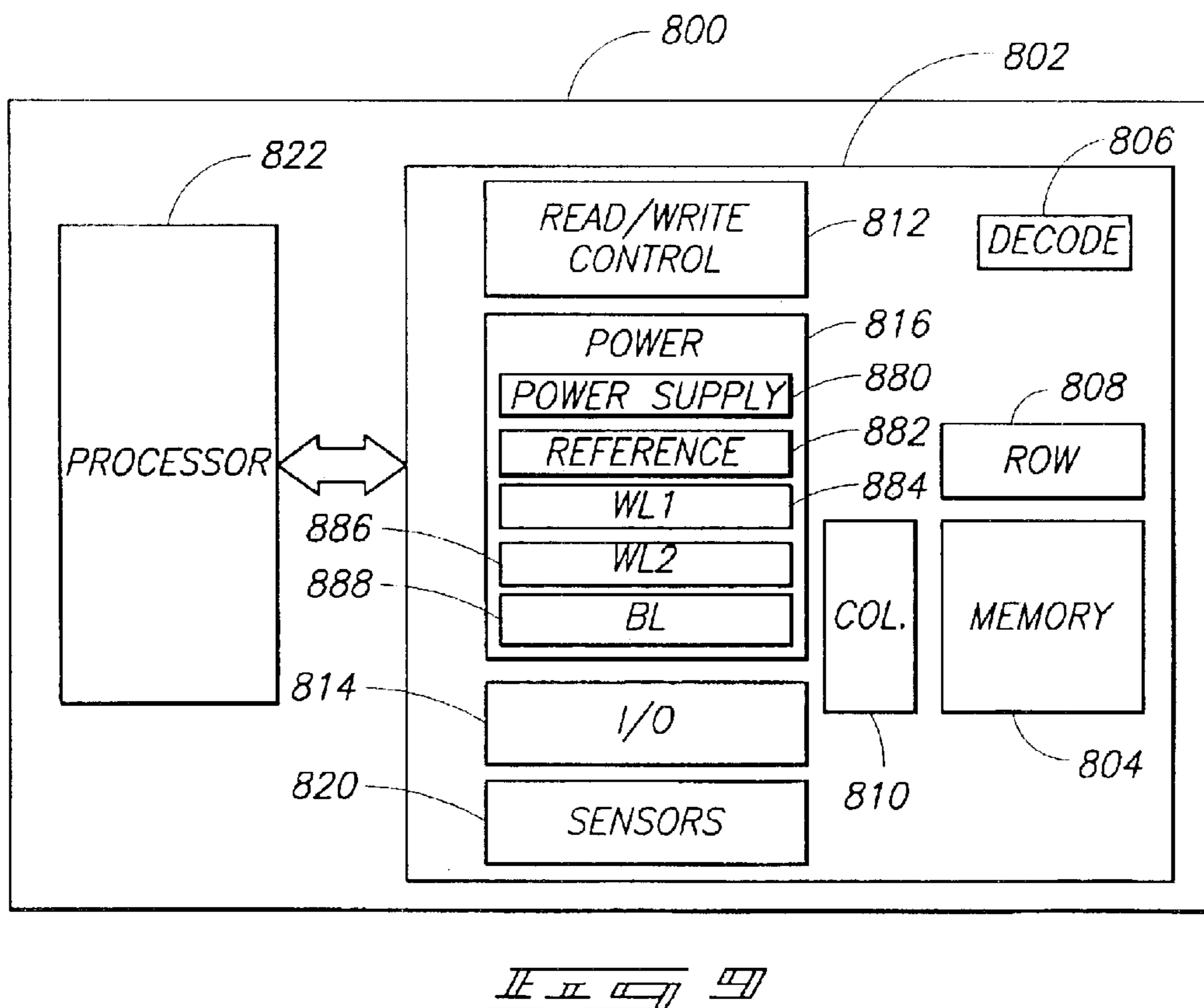
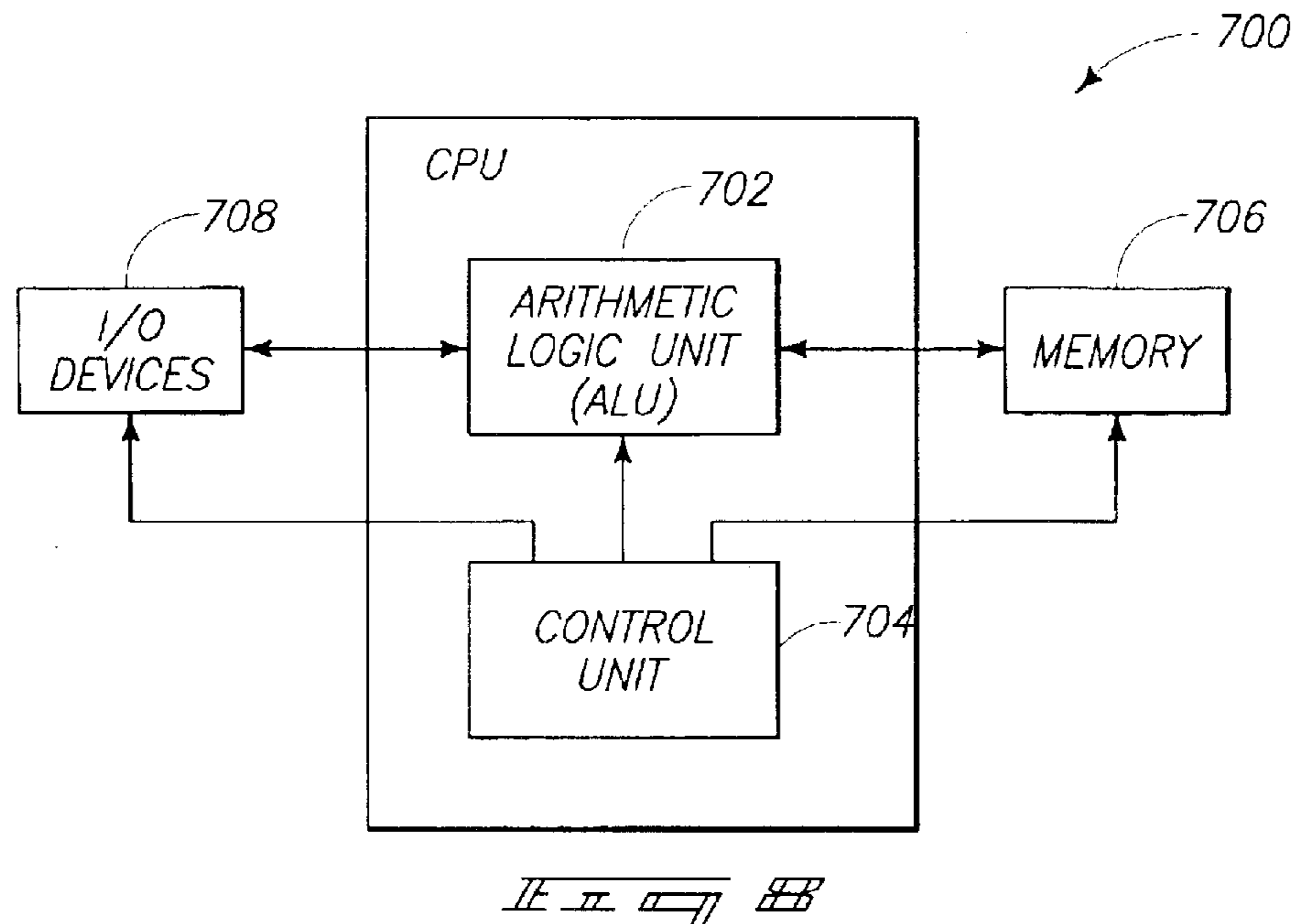


*Fig. 4*

*404*



*Fig. 5*



# METHODS OF FORMING RUGGED SEMICONDUCTOR-CONTAINING SURFACES

## TECHNICAL FIELD

The invention pertains to semiconductor structures containing rugged semiconductor materials, and pertains to methods of forming rugged semiconductor-containing surfaces.

## BACKGROUND OF THE INVENTION

Rugged semiconductor surfaces are frequently utilized in applications in which it is desired to have an increased surface area. For instance, rugged semiconductor materials are frequently utilized as storage nodes in capacitor constructions.

The semiconductor of a rugged semiconductor material can comprise, consist essentially of, or consist of any element known to have semiconductive properties. The semiconductor will frequently comprise, consist essentially of, or consist of silicon. In applications in which the semiconductor consists essentially of, or consists of silicon, the rugged semiconductor material can be referred to as rugged silicon, and in exemplary applications can be hemispherical grain (HSG) silicon.

Although techniques are known for forming rugged semiconductor surfaces, there is a continuing need to develop improved methodologies for controlling the particular topography associated with a rugged semiconductor surface. In other words, there is a continuing need for controlling the ruggedness of the surfaces. Accordingly, it is desired to develop improved methods for forming rugged semiconductor surfaces.

## SUMMARY OF THE INVENTION

In one aspect, the invention encompasses a semiconductor structure. Such structure includes a stack comprising at least three semiconductor layers over a substrate. Two of the three semiconductor layers are adjacent one another, and an interface layer is between the adjacent semiconductor layers. The interface layer can have a thickness of less than or equal to about 10 Å, and can comprise insulative, semiconductive or conductively-doped semiconductive materials. A bottom of the stack is conductively-doped semiconductor material, and a top of the stack comprises a rugged semiconductor-containing surface.

In another aspect, the invention encompasses a method of forming a rugged semiconductor-containing surface. A first semiconductor layer is formed over a substrate, and a second semiconductor layer is formed over the first semiconductor layer. Subsequently, a third semiconductor layer is formed over the second semiconductor layer. Semiconductor-containing seeds are formed over the third semiconductor layer. The seeds are annealed to form the rugged semiconductor-containing surface. The first, second and third semiconductor layers are part of a common stack, and can be together utilized within a storage node of a capacitor construction.

In another aspect, the invention encompasses a method of forming rugged silicon. Silicon-containing seeds are grown over a semiconductor layer. The growing of the seeds comprises two or more depositions of the silicon of the seeds, with the depositions differing relative to one another in at least one process parameter. Such process parameter

can include, for example, a relative time of the depositions, and/or a relative vacuum utilized during the depositions.

## BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

FIG. 1 is a diagrammatic, cross-sectional view of a semiconductor wafer fragment at a preliminary stage of an exemplary method of the present invention.

FIG. 2 is a view of the FIG. 1 wafer fragment shown at a processing stage subsequent to that of FIG. 1.

FIG. 3 is a view of the FIG. 1 wafer fragment shown at a processing stage subsequent to that of FIG. 2.

FIG. 4 is a view of a semiconductor wafer fragment shown at a preliminary processing stage in accordance with an exemplary second embodiment of the present invention.

FIG. 5 is a diagrammatic, cross-sectional view of a semiconductor wafer fragment illustrating an exemplary DRAM cell formed in accordance with an aspect of the present invention.

FIG. 6 is a diagrammatic view of a computer illustrating an exemplary application of the present invention.

FIG. 7 is a block diagram showing particular features of the motherboard of the FIG. 6 computer.

FIG. 8 is a high-level block diagram of an electronic system according to an exemplary aspect of the present invention.

FIG. 9 is a simplified block diagram of an exemplary electronic system according to an aspect of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

As discussed in the "Background" section of this disclosure, it is difficult to control the relative size and shape of topographical features when utilizing prior art processes to form rugged semiconductor surfaces (such as, for example, hemispherical grain polysilicon surfaces). One aspect of the present invention is to utilize pulsing processes to provide control of topographical features associated with rugged semiconductor materials. Such control can allow increased surface area to be accomplished, which can lead to improved devices. For instance, the increased surface area can be utilized in a storage node of a container capacitor, which can lead to higher capacitance for the structure than would be obtained if prior art rugged semiconductor structures were utilized.

In order to assist the reader in understanding the process of the present invention, a brief discussion of particular differences between an exemplary embodiment of the present invention and the prior art is provided. A typical prior art process for forming HSG silicon is as follows. Initially, doped polysilicon is provided. An undoped layer of smooth polysilicon is then formed over and physically against the doped polysilicon. Subsequently, the undoped silicon is exposed to a seeding process. The seeding is accomplished in one step, in that seeding materials are provided for an appropriate period of time, and under an appropriate vacuum to form the seeds as a single layer.

Subsequently, the seeds and underlying silicon layers are annealed to form the rugged silicon. The seeds and undoped silicon can be doped during the annealing process by out-diffusion of dopant from the underlying doped silicon. Alternatively, and/or additionally, dopant can be implanted into the seeds and undoped silicon to conductively dope the seeds and underlying undoped silicon. The dopant implanting can occur at any suitable time relative to the annealing, including before or after the annealing.

In particular aspects, the present invention differs from the prior art processes in that multiple doped silicon layers can be provided utilizing a pulsed process, and/or multiple non-conductively-doped silicon layers can be provided in a pulsed process. The various layers can differ from one another in the composition of semiconductor material. Also, if the various layers are conductively-doped layers, the layers can differ from one another in the concentration, type and/or chemical constituency of the dopant materials. In particular aspects, interface layers can be provided between one or more of the pulse-deposited layers. The interface layers can be very thin (with exemplary interface layers being less than 10 Å thick, and in some cases being less than 5 Å thick). The interface layers can be utilized as barriers to alleviate and/or prevent dopant migration between adjacent layers during the seeding and/or annealing stages. Additionally, and/or alternatively, the interface layers can be utilized to prevent cross diffusion of constituent materials of the various semiconductor layers during the annealing and/or seeding.

The invention can also include a pulsed process for forming the seeds. Specifically, the seeds can be formed in multiple steps, with the steps varying from one another in one or more process parameters. For instance, a first layer of the seeds can be formed under a first vacuum condition for a first deposition time, and subsequently a second seed layer can be formed under a second vacuum condition which is different than the first, and for a second time which may also be different than the first. The different process parameters could also encompass utilization of different precursors, so that various layers of the seed differ in chemical constituency relative to one another.

The pulsing processes utilized in methodology of the present invention can change a bonding structure of an atom bonding network (Si—Si, Si—P, etc.), and can thus affect rugged semiconductor formation. Temperature, time, pressure, gas flow rate and/or other conditions can be changed during formation of the various base semiconductor layers (either conductively-doped or undoped base layers), as well as during formation of the seeds. Variation of the various parameters can allow optimization of rugged silicon shape, density and size to be achieved for a particular application. Such can allow a rugged semiconductor material to be formed having a larger surface area than prior art materials, and also to be formed having topographical features which allow the surface to be better optimized for a particular application. For instance, a rugged semiconductor surface formed in accordance with the present invention can be included within a capacitor as a storage node, and can allow a larger capacitance to be achieved from the capacitor than could be achieved utilizing rugged semiconductor materials formed in accordance with prior art methodologies.

Various exemplary aspects of the invention are described with reference to FIGS. 1–3.

Referring initially to FIG. 1, a construction **10** is illustrated at a preliminary processing stage of an exemplary

aspect of the present invention. Construction **10** comprises a substrate **12** which can be, for example, a semiconductor substrate. To aid in interpretation of the claims that follow, the terms “semiconductive substrate” and “semiconductor substrate” are defined to mean any construction comprising semiconductive material, including, but not limited to, bulk semiconductive materials such as a semiconductive wafer (either alone or in assemblies comprising other materials thereon), and semiconductive material layers (either alone or in assemblies comprising other materials). The term “substrate” refers to any supporting structure, including, but not limited to, the semiconductive substrates described above. Although substrate **12** is shown as a single mass, it is to be understood that the substrate can comprise numerous discrete materials. For instance, substrate **12** can comprise an insulative material over monocrystalline silicon.

A stack **14** is formed over substrate **12**. The exemplary stack comprises a pair of conductively-doped semiconductor layers (**16** and **18**); a pair of semiconductor layers which are not conductively-doped (**20** and **22**); and an interface layer **24** between the upper conductively-doped layer **18** and the lower layer **20** which is not conductively-doped.

The shown stack **14** can be considered to comprise at least three semiconductor layers, and in the shown aspect comprises four semiconductor layers. The various layers can be considered to be a first, second, third and fourth semiconductor layer, which are formed over one another. The layers **16**, **18**, **20**, **22** and **24** which are part of the common stack **14** can be ultimately incorporated into a single circuit device. For instance, the layers can be incorporated into a capacitor and comprised by a storage node of the capacitor.

The semiconductor material of layers **16**, **18**, **20** and **22** can comprise any suitable semiconductive element, including, for example, one or both of silicon and germanium.

Conductively-doped layers **16** and **18** differ from one another, and can be distinguished from one another. The difference between layers **16** and **18** can be anything which enables the layers to be distinguished from one another, including, for example, (1) one or more of a relative dopant concentration between the layers; (2) a majority dopant type within the layers (for instance, one of the layers can be majority p-type and the other can be majority n-type); (3) the chemical composition of the dopant (for instance, both layers can comprise the same majority dopant type, but can differ from one another in terms of the actual dopant utilized, for instance, if both are n-type majority doped, one can predominately comprise phosphorous and the other predominately comprise arsenic); and (4) the chemical composition of the semiconductor (for instance, one of the layers can comprise silicon/germanium while the other consists of silicon, or both layers can comprise silicon/germanium with the relative amount of germanium differing between the layers).

Layers **16** and **18** can be formed in what can be considered a pulsed process, with layer **16** being first deposited, then one or more process parameters being changed and layer **18** being subsequently deposited. Layers **16** and **18** can be deposited in the same reaction chamber, and within a continuous process occurring without breaking vacuum to the deposition chamber. Layers **16** and **18** can be formed by atomic layer deposition (ALD) processes, chemical vapor deposition process (CVD), or combinations of these and/or other suitable processes. Layers **16** and **18** can be formed to thickness of from about 40 Å to about 1000 Å, and in typical processing each will have a thickness of about 40 Å.



Layers **20** and **22** can differ from one another in any property that enables layers **20** and **22** to be distinguished from one another. For instance, layers **20** and **22** can differ from one another in terms of the semiconductor composition of the layers. One of the layers can comprise silicon/  
 5 germanium and the other can consist of silicon. Alternatively, both of the layers can comprise silicon/  
 germanium, with the relative amount of germanium differ-  
 ing in one layer relative to the other. Layers **20** and **22** can  
 comprise thicknesses of from about 40 Å to about 1000 Å,  
 10 and typically each will have a thickness of about 40 Å. Layers **20** and **22** can be formed by any suitable process,  
 including ALD, CVD and/or other processes.

It is noted that layers **20** and **22** are referred to as being not conductively-doped, and such term should not be under-  
 15 stood to mean that the layers **20** and **22** contain absolutely no dopant. Rather, a layer which is not conductively-doped is, as is understood in the art, a layer which can contain some dopant, but which contains too little dopant to be considered electrically conductive.

In the discussion above, it should be understood that the semiconductor material of layers **16,18, 20** and **22** can  
 20 comprise any element, or combination of elements known to be semiconductive, and in particular aspects can comprise, consist essentially of, or consist of silicon; or in other exemplary aspects can comprise, consist essentially of, or consist of silicon/germanium.

Interface layer **24** separates doped layer **18** from the adjacent layer **20** that is not conductively-doped, and in the shown aspect of the invention is the only material between  
 25 layers **18** and **20**. Interface layer **24** can comprise silicon dioxide, silicon nitride, silicon oxynitride, silicon, germanium, and/or silicon/germanium. If layer **24** comprises a semiconductor, the semiconductor can be, in particular aspects, conductively-doped.

In some applications, layer **24** can consist essentially of, or consist of an insulative material which can function as a dopant barrier between conductively-doped layer **18** and the non-conductively-doped layer **20**, and in such aspects can  
 35 comprise, consist essentially of, or consist of silicon dioxide, silicon nitride or silicon oxynitride.

Layer **24** can be formed over layer **18** by, for example, oxidation of semiconductor material of layer **18**, nitridation of the semiconductor material layer **18**, or by ALD or CVD of a desired material over layer **18**.

In particular aspects, layer **24** has a thickness of less than 10 Å, and more preferably less than 5 Å. A reason for keeping layer **24** thin is so that the layer does not subsequently impede conductivity between layers **18** and **20** in a device ultimately formed to comprise stack **14**. Specifically,  
 40 if stack **14** is ultimately utilized to form a rugged semiconductor surface, it can be desired to subsequently dope layers **20** and **22** so that an entirety of stack **14** is conductively-doped. It can also be desired to have relatively unimpeded electrical conductance from layer **16** to layer **22**. Accordingly, it can be desired to have layer **24** formed thin enough so that the layer does not ultimately impede electrical conductance between layers **16** and **22** in a circuit device incorporating stack **14**.

A reason for utilizing interface layer **24** at initial processing stages of forming rugged silicon from stack **14** is that it can be difficult to control fabrication of a rugged semiconductor if dopant migrates from the lower doped portions of the stack to the upper portions of the stack during fabrication of the rugged surface. Specifically, the dopant can interfere  
 45 with the fabrication of the rugged surface, and ultimately affect the resulting topography of the rugged surface.

One solution which would appear to avoid migration of dopant into layers **20** and **22** without utilization of interface layer **24** is to simply not provide any conductively-doped layers within stack **14**. However, such solution is typically  
 5 not practical in that a rugged semiconductor formed utilizing layer **14** is usually intended to be a conductively-doped material throughout an entirety of its thickness (for instance, the rugged material will frequently be utilized as a storage node of a capacitor), and it is generally impractical to implant a conductivity-enhancing dopant through an entire  
 10 thickness of the rugged material. Accordingly, the application of the rugged material typically starts with a lower portion of the stack utilized for forming the rugged material being conductively-doped so that the lower portion of the rugged semiconductive material later formed from the stack will have the appropriate conductivity doping without need for an implant to penetrate the entire thickness of the stack.

In the shown application, the conductively-doped portion of stack **14** is approximately the lower half of the stack. It is to be understood, however, that in other applications the  
 15 conductively-doped portion can be less than half the thickness of the stack, and in yet other applications the conductively-doped portion can be more than half the thickness of the stack.

Although interface layer **24** is shown between a conductively-doped layer **18** and a layer **20** which is not conductively-doped, it is to be understood that layer **24** can be formed between conductively-doped layers additionally and/or alternatively to its formation between a conductively-  
 20 doped layer and a layer not conductively-doped; and also that layer **24** can be formed between a pair of semiconductor layers which are not conductively-doped additionally and/or alternatively to its formation between a conductively-doped layer and a layer which is not conductively-doped. An advantage to forming an interface layer between a pair of  
 25 layers which are conductively-doped is that the interface layer can prevent dopant migration between the conductively-doped layers to the extent that the layers comprise dopants having different chemical constituencies relative to one another. Also, even if layer **24** is not a dopant barrier layer, the layer can be utilized to modify a behavior of stack **14** during formation of rugged silicon, which can provide additional control of the fabrication of the rugged silicon.

An advantage to forming interface layer **24** between a pair of semiconductor layers which are not conductively-doped is that the interface layer can be a dopant barrier layer which allows the lower of the non-conductively-doped layers to become conductively-doped through out-diffusion from  
 30 conductively-doped layers below such non-conductively-doped layer, while preventing out-diffusion into the upper non-conductively-doped layer. Alternatively, if layer **24** is not a dopant barrier layer, there can still be advantages to utilizing such layer between the non-conductively-doped layers in that layer **24** can modify behavior of stack **14** during fabrication of rugged semiconductor materials, which can provide additional control of the fabrication of the semiconductor materials.

It is emphasized that although the invention is described as growing a stack upwardly, with lower portions of the stack being conductive and upper portions of the stack being non-conductive, the relative orientations of the non-conductive portions and conductively-doped portions can be changed depending on the orientation of the substrate. Accordingly, the non-conductively-doped portions can be  
 35 formed laterally outward of conductively-doped portions, or even downwardly of conductively-doped portions in various

aspects of the invention. Further, the directional terms upwardly, downwardly, and laterally outwardly are, unless specified otherwise, defined relative to the substrate itself, rather than relative to an outside observer. Accordingly, a layer which is formed over another in the context of this invention, may actually appear to be formed below the other to an observer, depending on the frame of reference of the observer to the substrate.

Although stack **14** is shown to comprise conductively-doped semiconductor materials adjacent one another in one portion of the stack, and non-conductively-doped portions adjacent one another in another portion of the stack, it is to be understood that the conductively-doped portions and non-conductively-doped portions can alternate with one another within the stack in various aspects of the invention. However, a portion of stack **14** most proximate to the supporting substrate **12** will typically be conductively-doped, and the portion having an exposed surface will typically be non-conductively-doped. Accordingly, the shown lowermost portion **16** is conductively-doped, and the shown uppermost portion **22** is not conductively-doped.

The total number of semiconductor layers **16,18, 20** and **22** utilized in stack **14** (i.e. the layers typically having a thickness of from 40 Å to 1000 Å) will typically be from about 4 to about 10, with from about 2 to about 5 conductively-doped layers typically being utilized, and from about 2 to about 5 non-conductively-doped layers typically being utilized. The total number of interface layers can therefore typically be from about 1 to about 9.

Referring to FIG. 2, seeds **31, 33, 35,** and **37** are formed over an exposed upper surface of non-conductively-doped semiconductor layer **22**, and in the shown embodiment are formed physically against the upper surface of layer **22**. Since layers **16, 18** and **20** are covered by layer **22**, the seeds are not formed against any surfaces of layers **16,18** and **20**. Seeds **31, 33, 35** and **37** comprise semiconductor material, and in particular aspects can comprise, consist essentially of, or consist of silicon. The seeds comprise multiple layers **32, 34** and **36**. The various layers are distinguishable from one another in at least one property. Such property can be a physical parameter (such as, for example, density), and/or a chemical parameter (such as, for example, composition). The various layers of the seeds are formed by growing the seeds in multiple depositions, with the depositions differing relative to one another in at least one process parameter. In the shown exemplary aspect of the invention, the seeds have been grown with three different depositions to form three different layers. However, it is to be understood that the seeds can be grown generally with two or more depositions.

The different process parameter utilized in growing one layer of the seeds relative to another can include, for example, a relative time of the deposition, a relative vacuum utilized during the deposition, and/or a change in the composition of precursor utilized in the deposition. A change in vacuum and/or deposition time can result in a change of density of a layer relative to previously-deposited layers, and a change in precursor composition can result in a change of the chemical composition of the layer relative to previously deposited layers. The vacuum utilized in forming layers **32, 34** and **36** will typically be from about 1 mTorr to about 50 mTorr and a deposition time will typically be from about 1 minute to about 5 minutes. The precursor can be a silicon-containing material (such as silane), a germanium-containing material, or a combination of silicon-containing materials and germanium-containing materials. The total number of layers formed for given seed will typically be formed within a total time of about 15 minutes.

The utilization of multiple different layers within the seeds can enable control of shape and density of the seeds, which ultimately enables additional control of the topography of a rugged semiconductor surface formed utilizing the seeds.

After seeds **31, 33, 35** and **37** are formed, construction **10** is subjected to an appropriate anneal to form a rugged semiconductor surface from the seeds. Such anneal will typically be conducted for a time of about 30 minutes at a temperature of from about 550° C. to about 610° C., under an appropriate inert gas (such as, for example, N<sub>2</sub>, He, or H<sub>2</sub>). Also, seeds **31, 33, 35** and **37**, together with non-conductively doped layers **20** and **22**, will be subjected to an implant of conductivity-enhancing dopant to convert layers **20, 22, 32, 34** and **36** to electrically conductive materials. The doping can be conducted before or after the anneal.

FIG. 3 shows construction **10** after an appropriate anneal, and after the doping of layers **20, 22, 32, 34** and **36**. Seeds **31, 33, 35** and **37**, together with stack **14**, form a rugged semiconductor material **38** having a surface topography **40** which extends across exposed portions of layer **22** and exposed portions of layer **36**. It is to be understood, however, that in particular embodiments seeds **31, 33, 35** and **37** can grow to contact one another, and accordingly there would not be exposed portions of layer **22** along the topographical surface.

Layers **16, 18, 20, 22, 24, 32, 34** and **36** are shown to remain distinguishable from one another in the final construction of FIG. 3. In some aspects of the invention, diffusion between various of the layers can cause differences between the layers to be reduced, or even eliminated, such that various of the layers are no longer distinguishable relative to one another at the final stage of the processing shown in FIG. 3. In other aspects, the differences can remain relative to at least some of the layers, so that at least some of the layers are distinguishable relative to one another at the processing stage of FIG. 3. Regardless, the utilization of multiple different layers in the processing sequence of FIGS. 1–3 can provide control of the surface topography of a rugged semiconductor material that does not exist in prior art processes.

FIG. 4 shows a construction **50** at a processing stage similar to that described previously with reference to FIG. 1, and in referring to construction **50** identical numbering will be utilized as was used above in describing construction **10** of FIG. 1, where appropriate. Construction **50** comprises a substrate **12**, and a stack **54** of various layers over substrate **12**. The layers within stack **54** are labeled as **56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78** and **80**. Layers **56, 60, 64** and **72** are conductively-doped semiconductor layers, which can comprise constructions identical to those described previously with reference to layers **16** and **18** of FIG. 1. Layers **58, 68, 76** and **80** are semiconductor layers which are not conductively-doped, and can comprise constructions identical to those described above with reference to layers **20** and **22** of FIG. 1. Layers **62, 66, 70, 74** and **78** are interface layers, and can comprise constructions identical to those described previously with reference to layer **24** of FIG. 1.

FIG. 4 illustrates that a non-conductively-doped semiconductor layer can be provided between a pair of conductively-doped semiconductor layers in particular aspects of the invention (for instance, layer **58** is between layers **56** and **60**). FIG. 4 also illustrates that a conductively-doped semiconductor layer can be provided between a pair of non-conductively-doped semiconductor materials in particular aspects of the invention, (for instance, layer **72** is between

layers **68** and **76**). Additionally, FIG. **4** illustrates that interface materials can be provided between a pair of conductively-doped semiconductor layers (for instance, layer **62** is between layers **64** and **66**), and that an interface material can be provided between a pair of non-conductively-doped semiconductor layers (for instance, interface layer **78** is between layers **76** and **80**).

Stack **54** can be subjected to processing similar to that described above with reference to FIGS. **2** and **3** to form a rugged semiconductor material comprising the various layers of stack **54**.

In exemplary aspects of the invention, the interface layers can be considered to separate adjacent semiconductor layers. In accordance with the above-described exemplary constructions of the semiconductor layers and interface layer, it is to be understood that numerous combinations of interface layers and semiconductor layers can be utilized in accordance with various aspects of the invention. For instance, the adjacent semiconductor layers can consist of silicon or doped silicon and the interface layer can comprise, consist essentially of, or consist of Si/Ge. Also, the adjacent semiconductor layers can be conductively-doped, and the interface layer can be a semiconductor material which is not conductively-doped. Such non-conductively-doped interface semiconductor material can comprise, for example, germanium and/or silicon.

FIG. **5** illustrates a semiconductor construction **100** comprising the rugged semiconductor material **38** of FIG. **3** incorporated into a DRAM cell **102**.

DRAM cell **102** comprises a substrate **104**. Substrate **104** can comprise, for example, lightly-doped monocrystalline silicon. A transistor device **106** is associated with substrate **104** and comprises a transistor gate **108** separated from substrate **104** by a suitable insulative material **110**, and a pair of source/drain regions **112** extending into substrate **104**. Although transistor gate **108** is shown to be homogeneously conductive, it is to be understood that the gate can, in accordance with conventional practices, comprise multiple layers of conductive materials, and also that the gate can comprise an insulative cap (not shown) over a top of the gate. Sidewall spacers **114** are shown adjacent sidewalls of gate **108**.

A conductive pedestal **116** extends to electrically contact one of the source/drain regions **112**.

An insulative material **118** is over gate **108**, and an opening **120** extends through insulative material **118** to conductive pedestal **116**.

Rugged semiconductor material **38** is formed within opening **120** to define a storage node of a container capacitor construction.

A dielectric material **122** extends within opening **120** and conformally along the roughened surface **40** of rugged semiconductor construction **38**.

A second capacitor electrode **124** is provided over dielectric material **122** and separated from the first capacitor electrode (i.e. the storage node comprising construction **38**) by the dielectric material **122**.

Dielectric material **122** can comprise any suitable dielectric material, including, for example, silicon nitride, silicon dioxide, or various high-k materials. Capacitor electrode **124** can comprise any suitable electrically conductive material, including, for example, various metals, metal compounds, and/or conductively-doped semiconductor materials.

Storage node **38**, dielectric material **122** and capacitor electrode **124** together define a capacitor construction **126**

which is in electrical connection with one of the source/drains of transistor device **106**. The other of the source/drains **112** is in electrical connection with a bitline **128**.

Utilization of methodology of the present invention enables the ruggedness of surface **40** to be better controlled than it could be utilizing prior art processes. Such can enable capacitor construction **126** to have a higher capacitance than a capacitor formed in the same opening utilizing a storage node formed in accordance with prior art processes. As discussed previously, surface **40** can consist of a surface of the seeds **31**, **33**, **35** and **37** described previously with reference to FIGS. **2** and **3**, or can comprise surfaces of the seeds together with a surface of semiconductor material **22**. In either event, rugged surface **40** can comprise silicon, consist essentially of silicon, or consist of silicon.

A circuit device comprising rugged semiconductor material formed in accordance with methodology of the present invention can be utilized in numerous assemblies, including, for example, computer systems and other electronic systems.

FIG. **6** illustrates generally, by way of example, but not by way of limitation, an embodiment of a computer system **400** according to an aspect of the present invention. Computer system **400** includes a monitor **401** or other communication output device, a keyboard **402** or other communication input device, and a motherboard **404**. Motherboard **404** can carry a microprocessor **406** or other data processing unit, and at least one memory device **408**. Memory device **408** can comprise various aspects of the invention described above, including, for example, the DRAM unit cell described with reference to FIG. **5**. Memory device **408** can comprise an array of memory cells, and such array can be coupled with addressing circuitry for accessing individual memory cells in the array. Further, the memory cell array can be coupled to a read circuit for reading data from the memory cells. The addressing and read circuitry can be utilized for conveying information between memory device **408** and processor **406**. Such is illustrated in the block diagram of the motherboard **404** shown in FIG. **7**. In such block diagram, the addressing circuitry is illustrated as **410** and the read circuitry is illustrated as **412**.

In particular aspects of the invention, memory device **408** can correspond to a memory module. For example, single in-line memory modules (SIMMs) and dual in-line memory modules (DIMMs) may be used in the implementation which utilize the teachings of the present invention. The memory device can be incorporated into any of a variety of designs which provide different methods of reading from and writing to memory cells of the device. One such method is the page mode operation. Page mode operations in a DRAM are defined by the method of accessing a row of a memory cell arrays and randomly accessing different columns of the array. Data stored at the row and column intersection can be read and output while that column is accessed.

An alternate type of device is the extended data output (EDO) memory which allows data stored at a memory array address to be available as output after the addressed column has been closed. This memory can increase some communication speeds by allowing shorter access signals without reducing the time in which memory output data is available on a memory bus. Other alternative types of devices include SDRAM, DDR SDRAM, SLDRAM, VRAM and Direct RDRAM, as well as others such as SRAM or Flash memories.

FIG. **8** illustrates a simplified block diagram of a high-level organization of various embodiments of an exemplary

electronic system **700** of the present invention. System **700** can correspond to, for example, a computer system, a process control system, or any other system that employs a processor and associated memory. Electronic system **700** has functional elements, including a processor or arithmetic/logic unit (ALU) **702**, a control unit **704**, a memory device unit **706** and an input/output (I/O) device **708**. Generally, electronic system **700** will have a native set of instructions that specify operations to be performed on data by the processor **702** and other interactions between the processor **702**, the memory device unit **706** and the I/O devices **708**. The control unit **704** coordinates all operations of the processor **702**, the memory device **706** and the I/O devices **708** by continuously cycling through a set of operations that cause instructions to be fetched from the memory device **706** and executed. In various embodiments, the memory device **706** includes, but is not limited to, random access memory (RAM) devices, read-only memory (ROM) devices, and peripheral devices such as a floppy disk drive and a compact disk CD-ROM drive. One of ordinary skill in the art will understand, upon reading and comprehending this disclosure, that any of the illustrated electrical components are capable of being fabricated to include DRAM cells in accordance with various aspects of the present invention.

FIG. **9** is a simplified block diagram of a high-level organization of various embodiments of an exemplary electronic system **800**. The system **800** includes a memory device **802** that has an array of memory cells **804**, address decoder **806**, row access circuitry **808**, column access circuitry **810**, read/write control circuitry **812** for controlling operations, and input/output circuitry **814**. The memory device **802** further includes power circuitry **816**, and sensors **820**, such as current sensors for determining whether a memory cell is in a low-threshold conducting state or in a high-threshold non-conducting state. The illustrated power circuitry **816** includes power supply circuitry **880**, circuitry **882** for providing a reference voltage, circuitry **884** for providing the first wordline with pulses, circuitry **886** for providing the second wordline with pulses, and circuitry **888** for providing the bitline with pulses. The system **800** also includes a processor **822**, or memory controller for memory accessing.

The memory device **802** receives control signals from the processor **822** over wiring or metallization lines. The memory device **802** is used to store data which is accessed via I/O lines. It will be appreciated by those skilled in the art that additional circuitry and control signals can be provided, and that the memory device **802** has been simplified to help focus on the invention. At least one of the processor **822** or memory device **802** can include a DRAM cell of the type described previously in this disclosure.

The various illustrated systems of this disclosure are intended to provide a general understanding of various applications for the circuitry and structures of the present invention, and are not intended to serve as a complete description of all the elements and features of an electronic system using memory cells in accordance with aspects of the present invention. One of the ordinary skill in the art will understand that the various electronic systems can be fabricated in single-package processing units, or even on a single semiconductor chip, in order to reduce the communication time between the processor and the memory device (s).

Applications for memory cells can include-electronic systems for use in memory modules, device drivers, power modules, communication modems, processor modules, and application-specific modules, and may include multilayer,

multichip modules. Such circuitry can further be a subcomponent of a variety of electronic systems, such as a clock, a television, a cell phone, a personal computer, an automobile, an industrial control system, an aircraft, and others.

In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.

The invention claimed is:

**1.** A method of forming a rugged semiconductor-containing surface comprising:

forming a first semiconductor layer over a substrate;

forming a second semiconductor layer over the first semiconductor layer;

forming a third semiconductor layer over the second semiconductor layer;

wherein the first, second and third semiconductor layers are part of a common stack ultimately incorporated into a single circuit device;

forming semiconductor-containing seeds against a surface of the third semiconductor layer, and not against surfaces of the first and second semiconductor layers;

annealing the seeds to form the rugged semiconductor-containing surface; and

wherein the first and second semiconductor layers are conductively-doped and differ from one another at least in terms of the chemical composition of the semiconductor.

**2.** The method of claim **1** wherein the circuit device is a capacitor, and wherein the common stack is comprised by a storage node of the capacitor.

**3.** The method of claim **1** wherein the semiconductor of the first, second and third semiconductor layers includes silicon.

**4.** The method of claim **1** wherein the semiconductor of the seeds includes silicon.

**5.** The method of claim **1** wherein the semiconductor of the seeds consists essentially of silicon.

**6.** The method of claim **1** wherein the semiconductor of the seeds consists of silicon.

**7.** The method of claim **1** wherein the first, second and third semiconductor layers each have a thickness of from about 40 Å to about 1000 Å.

**8.** The method of claim **1** further comprising forming an interface material having a thickness of less than 10 Å over the first semiconductor layer, and wherein the first and second semiconductor layers are separated from one another by only the layer of interface material having a thickness of less than 10 Å.

**9.** The method of claim **1** wherein the first and second semiconductor layers further differ from one another in terms of the majority dopant type.

**10.** A method of forming rugged silicon, comprising growing silicon-containing seeds over a semiconductor layer, the growing comprising two or more depositions of the silicon of the seeds with the depositions differing relative to one another in at least one process parameter, and wherein the at least one process parameter includes one or more of a precursor composition, a relative time of the depositions, and a relative vacuum utilized during the depositions.

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11. The method of claim 10 wherein the silicon-containing seeds consist essentially of silicon.

12. The method of claim 10 wherein the silicon-containing seeds consist of silicon.

13. The method of claim 10 wherein the at least one process parameter includes a precursor composition.

14. The method of claim 10 wherein the at least one process parameter includes a relative time of the depositions.

15. The method of claim 10 wherein the at least one process parameter includes a relative vacuum utilized during the depositions.

16. The method of claim 10 further comprising annealing the seeds at a temperature of from about 560° C. to about 610° C.

17. A method of forming a rugged silicon-containing material, comprising:

forming a stack comprising two or more conductively-doped semiconductor layers and two or more semiconductor layers which are not conductively-doped over a substrate; the bottom layer of the stack being one of the conductively-doped semiconductor layers and the top layer of the stack being one of the layers which is not conductively-doped;

forming silicon-containing seeds over the top layer of the stack;

annealing the seeds to form the rugged silicon-containing material; and

wherein at least two of the two or more conductively-doped layers differ from one another at least in terms of the chemical composition of the semiconductor layers.

18. The method of claim 17 wherein at least two of the two or more conductively-doped layers differ from one another at least in terms of dopant concentration.

19. The method of claim 17 wherein at least two of the two or more conductively-doped layers differ from one another at least in terms of the majority dopant type.

20. The method of claim 17 wherein the lowest of the semiconductor layers which are not conductively-doped is above the uppermost conductively-doped semiconductor layer.

21. The method of claim 17 wherein one or more of the semiconductor layers which are not conductively-doped are between at least a pair of the conductively-doped semiconductor layers.

22. The method of claim 17 wherein one or more of the conductively-doped semiconductor layers is between at least a pair of the semiconductor layers which are not conductively-doped.

23. The method of claim 17 further comprising forming an interface material having a thickness of less than or equal to about 10 Å between an adjacent pair of the semiconductor layers.

24. The method of claim 23 wherein the interface material has a thickness of less than or equal to about 5 Å.

25. The method of claim 23 wherein both semiconductor layers of the adjacent pair are not conductively-doped.

26. The method of claim 23 wherein both semiconductor layers of the adjacent pair are conductively-doped.

27. The method of claim 23 wherein one semiconductor layer of the adjacent pair is conductively-doped and the other semiconductor layer of the adjacent pair is not conductively-doped.

28. A method of forming a rugged silicon-containing material, comprising:

forming a stack comprising two or more conductively-doped semiconductor layers and two or more semicon-

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ductor layers which are not conductively-doped over a substrate; the bottom layer of the stack being one of the conductively-doped semiconductor layers and the top layer of the stack being one of the layers which is not conductively-doped;

forming silicon-containing seeds over the top layer of the stack;

annealing the seeds to form the rugged silicon-containing material; and

wherein the forming the seeds comprises two or more depositions of the silicon of the seeds, the depositions differing relative to one another in a relative time of the depositions.

29. A method of forming a rugged silicon-containing material, comprising:

forming a stack comprising two or more conductively-doped semiconductor layers and two or more semiconductor layers which are not conductively-doped over a substrate; the bottom layer of the stack being one of the conductively-doped semiconductor layers and the top layer of the stack being one of the layers which is not conductively-doped;

forming silicon-containing seeds over the top layer of the stack;

annealing the seeds to form the rugged silicon-containing material; and

wherein the forming the seeds comprises two or more depositions of the silicon of the seeds, the depositions differing relative to one another in a relative vacuum utilized during the depositions.

30. A method of forming a rugged silicon-containing material, comprising:

forming a stack comprising two or more conductively-doped semiconductor layers and two or more semiconductor layers which are not conductively-doped over a substrate; the bottom layer of the stack being one of the conductively-doped semiconductor layers and the top layer of the stack being one of the layers which is not conductively-doped;

forming silicon-containing seeds over the top layer of the stack;

annealing the seeds to form the rugged silicon-containing material; and

wherein at least two of the two or more semiconductor layers which are not conductively-doped differ from one another at least in terms of the chemical composition of the semiconductor layers.

31. A method of forming a rugged silicon-containing material comprising:

forming a stack comprising at least three semiconductor layers over a substrate, two of the three semiconductor layers being adjacent one another;

forming at least one interface layer in the stack, the interface layer being between the adjacent semiconductor layers, the interface layer being formed after one of the adjacent layers and before the other of the adjacent layers;

forming silicon-containing seeds over the stack;

annealing the seeds to form the rugged silicon-containing material; and

wherein at least two of the three semiconductor layers are not conductively-doped and differ from one another at least in terms of the chemical composition of the semiconductor layers.

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32. The method of claim 31 wherein the interface layer has a thickness of less than or equal to about 10 Å.

33. The method of claim 31 wherein the interface layer has a thickness of less than or equal to about 5 Å.

34. The method of claim 31 wherein the adjacent layers 5 have thicknesses of from about 40 Å to about 1000 Å, and wherein the interface layer has a thickness of less than or equal to about 10 Å.

35. The method of claim 31 wherein the interface layer comprises silicon dioxide.

36. The method of claim 31 wherein the interface layer comprises silicon.

37. The method of claim 31 wherein the interface layer comprises silicon nitride.

38. The method of claim 31 wherein both semiconductor 15 layers of the adjacent pair are not conductively-doped.

39. The method of claim 31 wherein both semiconductor layers of the adjacent pair are conductively-doped.

40. The method of claim 31 wherein one semiconductor 20 layer of the adjacent pair is conductively-doped and the other semiconductor layer of the adjacent pair is not conductively-doped.

41. A method of forming a rugged silicon-containing material comprising:

forming a stack comprising at least three semiconductor 25 layers over a substrate, two of the three semiconductor layers being adjacent one another;

forming at least one interface layer in the stack, the interface layer being between the adjacent semiconductor 30 layers, the interface layer being formed after one of the adjacent layers and before the other of the adjacent layers;

forming silicon-containing seeds over the stack;

annealing the seeds to form the rugged silicon-containing 35 material; and

wherein the adjacent semiconductor layers consist of silicon or doped silicon, and the interface layer comprises Si/Ge.

42. A method of forming a rugged silicon-containing 40 material comprising:

forming a stack comprising at least three semiconductor layers over a substrate, two of the three semiconductor layers being adjacent one another;

forming at least one interface layer in the stack; the 45 interface layer being between the adjacent semiconductor layers, the interface layer being formed after one of the adjacent layers and before the other of the adjacent layers;

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forming silicon-containing seeds over the stack;

annealing the seeds to form the rugged silicon-containing material; and

wherein the adjacent semiconductor layers consist of silicon or doped silicon, and the interface layer consists essentially of germanium.

43. The method of claim 42 wherein the interface layer consists of germanium.

44. A method of forming a rugged silicon-containing material comprising:

forming a stack comprising at least three semiconductor layers over a substrate, two of the three semiconductor layers being adjacent one another;

forming at least one interface layer in the stack, the interface layer being between the adjacent semiconductor layers, the interface layer being formed after one of the adjacent layers and before the other of the adjacent layers;

forming silicon-containing seeds over the stack;

annealing the seeds to form the rugged silicon-containing material;

wherein the adjacent semiconductor layers are conductively-doped and the interface layer is a semiconductor material which is not conductively-doped; and

wherein the interface layer comprises germanium.

45. A method of forming a rugged silicon-containing material comprising:

forming a stack comprising at least three semiconductor layers over a substrate, two of the three semiconductor layers being adjacent one another;

forming at least one interface layer in the stack, the interface layer being between the adjacent semiconductor layers, the interface layer being formed after one of the adjacent layers and before the other of the adjacent layers;

forming silicon-containing seeds over the stack;

annealing the seeds to form the rugged silicon-containing material; and

wherein at least two of the three semiconductor layers are conductively-doped and differ from one another at least in terms of the chemical composition of the semiconductor layers.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 6,916,723 B2  
DATED : July 12, 2005  
INVENTOR(S) : Shenlin Chen et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 8,

Line 26, replace “not exposed portions of layer 22 along the topographical” with -- not be exposed portions of layer 22 along the topographical --.

Line 39, replace “of, multiple different layers in the processing sequence of” with -- of multiple different layers in the processing sequence of --.

Column 11,

Line 58, replace “present invention. One of the ordinary skill in the art will” with -- present invention. One of ordinary skill in the art will --.

Line 64, replace “Applications for memory cells can include-electronic” with -- Applications for memory cells can include electronic --.

Column 14,

Line 21, replace “conductively-doped semiconductor layers and the too” with -- conductively-doped semiconductor layers and the top --.

Signed and Sealed this

Thirtieth Day of May, 2006

A handwritten signature in black ink on a light gray dotted background. The signature reads "Jon W. Dudas" in a cursive style.

JON W. DUDAS

*Director of the United States Patent and Trademark Office*